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Assessing global popularity and threats to Important Bird and Biodiversity Areas using social media data

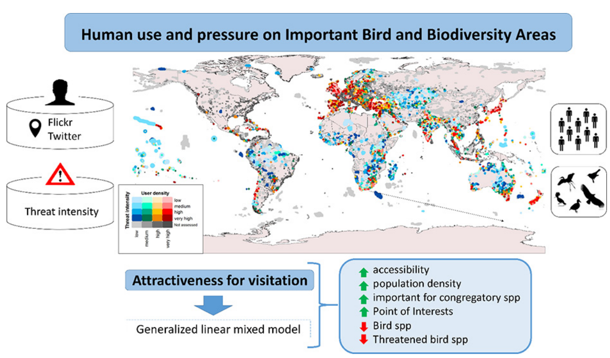
Anna Hausmann [a,b,*], Tuuli Toivonen [a,b], Christoph Fink [a,b], Vuokko Heikinheimo [a,b], Henrikki Tenkanen [a,b], Stuart H.M. Butchart [c,d], Thomas M. Brooks [e,f,g], Enrico Di Minin [a,b,h]

[a] *Department of Geosciences and Geography, University of Helsinki, FI-00014, Finland*
[b] *Helsinki Institute of Sustainability Science (HELSUS), University of Helsinki, FI-00014, Finland*
[c] *BirdLife International, David Attenborough Building, Pembroke Street, Cambridge CB2 3QZ, UK*
[d] *Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK*
[e] *International Union for Conservation of Nature, 28 Rue Mauverney, 1196 Gland, Switzerland*
[f] *World Agroforestry Center (ICRAF), University of the Philippines Los Baños, Laguna 4031, Philippines*
[g] *Institute for Marine & Antarctic Studies, University of Tasmania, Hobart, Tasmania 7001, Australia*
[h] *School of Life Sciences, University of KwaZulu-Natal, South Africa*

HIGHLIGHTS

- Understanding human use of sites of global biodiversity importance is crucial.
- We assessed potential interactions between humans and nature in Important Bird and Biodiversity Areas (IBAs).
- We used social media data to assess global visitation rates, attractiveness and pressure at IBAs.
- 17% of all IBAs assessed to be under very high threat also received high visitation rates.
- Social media provide new insights into human use at sites of biodiversity importance.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding worldwide patterns of human use of sites of international significance for biodiversity conservation is crucial for meeting global conservation targets. However, robust global datasets are scarce. In this study, we used social media data, mined from Flickr and Twitter, geolocated in Important Bird and Biodiversity Areas (IBAs) to assess i) patterns of popularity; ii) relationships of this popularity with geographical and biological variables; and iii) identify sites under high pressure from visitors. IBAs located in Europe and Asia, and in temperate biomes, had the highest density of users. Sites of importance for congregatory species, which were also more accessible, more densely populated and provided more tourism facilities, received higher visitation than did sites richer in bird species. We found 17% of all IBAs assessed to be under very high threat also received high visitation. Our results show in which IBAs enhanced monitoring should be implemented to reduce potential visitation risks to sites of conservation concern for birds, and to harness the potential benefits of tourism for conservation.

* Corresponding author at: Department of Geosciences and Geography, University of Helsinki, FI-00014, Finland.
E-mail address: anna.hausmann@helsinki.fi (A. Hausmann).

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1. Introduction

In the face of ongoing loss of biodiversity (Tittensor et al., 2014), conserving sites of biodiversity significance through protected areas and other measures is a key component of conservation strategies (CBD, 2011). Key Biodiversity Areas (KBAs) are sites contributing to the global persistence of biodiversity (IUCN, 2016), and among these, Important Bird and Biodiversity Areas (IBAs; that is, KBAs identified for birds) form by far the largest subset, with over 12,000 identified to date (Donald et al., 2018). Effectively managing and monitoring human activities in these sites is crucial for the persistence of species globally, and key for meeting global conservation targets (Butchart et al., 2012, 2015). However, robust datasets for assessing opportunities for and threats to biodiversity are scarce (Joppa et al., 2016).

Tourism is one of the fastest growing industries worldwide, and conservation areas are becoming popular destinations for people seeking nature-based experiences (Balmford et al., 2009). Nature-based tourism helps generate funding to (i) enhance management activities, species survival (Steven et al., 2013), and economic and political support for biodiversity conservation (Buckley, 2009); (ii) foster livelihoods of local stakeholders (Naidoo et al., 2011); (iii) increase environmental education and awareness (Ballantyne et al., 2011); and (iv) provide people with access to cultural services (e.g. sense of place, Hausmann et al., 2016), which enhance physical and psychological well-being.

Tourism may also have negative effects on biodiversity, e.g. by increasing disturbance to species and ecosystems, or by affecting the environment, e.g. pollution and habitat loss (Buckley, 2011). As the demand for nature-based tourism is increasing worldwide (Balmford et al., 2009), understanding patterns of popularity, causes of variation, and potential vulnerability to human activities in conservation areas is crucial to inform management (Steven et al., 2013). To assess global patterns of visitation in conservation areas, fine spatio-temporal information is needed. However, such information is scarce or missing, while implementing on-the-ground data collection, e.g. through traditional surveys, is expensive (Buckley, 2009) and limited in both space and time.

We live in the 'Information Age', an era where people are increasingly using digital sources, such as the internet, to access and share a wealth of information (Castells, 2010). In particular, billions of users share geolocated pictures, text and videos on social media platforms, such as Twitter and Flickr. People actively use social media for real-time sharing of their experiences during nature-based recreation (Hausmann et al., 2018), and such information can be used to assess human activities (Heikinheimo et al., 2017), and human-nature interactions (Di Minin et al., 2015) cost-effectively at an unprecedented spatio-temporal scale (Ladle et al., 2016). When tested against real-world data, geolocated data mined from social media have been found to be a robust indicator for human presence and spatial variation of visitation in protected areas at regional, national and global scale (Wood et al., 2013; Levin et al., 2015; Heikinheimo et al., 2017; Tenkanen et al., 2017). The content of online posts has also been validated as a reliable source of information to assess people's preferences for biodiversity (Hausmann et al., 2018) or cultural ecosystem services (Richard and Tunçer, 2017), and can be used to monitor public awareness of conservation (Roll et al., 2016; Correia et al., 2017; Cooper et al., 2019) and attractiveness of protected areas (Hausmann et al., 2017).

The potential for using social media data to assess use, attractiveness and pressure on key sites for biodiversity, at a global scale, has not been explored before. This study fills this gap by using geolocated posts from Flickr and Twitter in IBAs, to i) assess IBAs' popularity globally, continentally and at the biome level; ii) investigate which geographical and biological variables best explain IBA popularity globally, continentally and at the biome level; and iii) identify sites potentially under high pressure, by combining social media data with information on threat intensity, as assessed using in situ data.

2. Methods

2.1. Visitation patterns in IBAs

This study (see framework in Appendix S1, Supporting information) focuses on 12,765 terrestrial and marine IBAs (Birdlife International, 2014). Spatial maps showing the boundaries of IBAs were obtained from BirdLife International (2018a).

Metadata of social media posts was accessed from Application Programming Interfaces (APIs) of Flickr (https://www.flickr.com/services/api/) and Twitter (https://developer.twitter.com/en/docs). Information was obtained from publicly available posts geolocated within IBA boundaries, shared between February 2016 and June 2017. In order to account for differences in sizes of IBAs, the density of social media users/km^2 in each IBA was calculated. Information from social media was found in 95% (12,083) of all IBAs. The current analysis focuses on these IBAs only.

Differences in social media user densities globally, at continental (including high seas as a marine region) and biome level (Appendix S2, Supporting information) were investigated. Biomes (14 types worldwide) were grouped into 5 categories according to main climatic (rainfall and temperature annual distribution; see Appendix S3, Supporting information) characteristics (hereafter referred to as "biome groups"). In order to provide a standardized measure, IBAs were classified into low, medium, high and very high density of users according to quartiles of the overall distribution of densities. The proportion of IBAs found across different continents and biome groups for each density class was calculated. Non-parametric Kruskal-Wallis test and a post-hoc Dunn's pairwise z test were used to assess statistical differences between groups, as user density across IBAs was not normally distributed (Shapiro-Wilk $W = 0.996$, $p < 0.001$). All analyses were performed in R version 3.3.2 (R Development Core Team, 2013) and ArcGIS 10.3.1 (ESRI, 2011).

2.2. Potential predictors of attractiveness

Generalized linear mixed effect models (GLMMs) were used to assess whether geographical and biological variables, specific to each site, explained social media user densities across IBAs globally, and at the continent and biome level (see Appendices S3 and S4, Supporting information, for a full list of variables and for further details).

Previous studies have shown that more accessible natural areas receive higher visitation (Balmford et al., 2015) and greater frequency of social media use (Hausmann et al., 2017) compared with more remote sites. In order to assess whether accessibility explained social media user densities in IBAs, mean accessibility values (time of travel at 1 km resolution), within each site, were calculated from Weiss et al. (2018). Moreover, better provision of tourism facilities (e.g. accommodations, transport) relates to higher visitation in natural areas (De Vos et al., 2016). In this study, the density of tourism-related points of interest (POIs) (Appendix S5, Supporting information) at each site, collected from OpenStreetMap (https://www.openstreetmap.org/), was used to assess whether provision of such facilities also explained user densities. To our knowledge, this is the first time this dataset has been used to assess global visitation of relevance for conservation.

Furthermore, protected areas are essential for minimizing human pressure on the environment and reducing species extinction risk (Butchart et al., 2012). As not all IBAs are protected, the proportion of each IBA which overlapped with protected area boundaries in the World Database of Protected Areas (UNEP-WCMC, 2014) were calculated to assess whether exposure (i.e., no or lower protected area coverage) is related to density of users and potential pressure from visitation.

The socio-economic context in which protected areas are located affects tourists' visitation rates (Balmford et al., 2009), and use of social media (Hausmann et al., 2017). In order to assess whether users' densities in IBAs were higher in wealthier countries, Gross Domestic Product

(GDP) per capita for each country (from the World Bank database 2016) was also considered. Human population density also positively affects tourists' visitation rates (Balmford et al., 2015) and social media use in protected areas (Hausmann et al., 2017) as a consequence of enhanced mobile phone coverage (Aker and Mbiti, 2010). In order to assess whether human population density affected users' density in IBAs, mean population density were calculated within a 10 km buffer around each site from the Global Rural-Urban Mapping Project, Version 1 (GRUMPv1).

Natural areas with higher diversity of species receive higher tourism visitation rates (Siikamäki et al., 2015). Species richness was therefore considered as a potential predictor of higher social media use in IBAs. Overlaps between the distribution maps of 10,254 bird species (BirdLife International and Handbook of the Birds of the World, 2017) and the boundaries of each IBA were calculated. The resulting estimates are likely to contain large commission errors (i.e., erroneously list species as potentially occurring in IBAs where they do not actually occur) and to overestimate species richness in areas such as tropical mountains and archipelagos, which are also more remote and may receive lower visitation. However, given the large scale scope of our analyses, these errors are unlikely to bias our results. In order to assess whether user densities were higher in IBAs richer in threatened species, potential richness of 1460 bird species classified as Critically Endangered, Endangered, and Vulnerable by the IUCN Red List (BirdLife International, 2017) was also calculated. Further, areas of aggregations of particular species may be more attractive for birdwatchers and other tourists (Siikamäki et al., 2015). To determine whether user density was higher in IBAs which support resident or seasonal congregations of individuals of particular species, IBAs triggered by criterion A4 (i.e. sites holding >1% of the population of one or more species worldwide, either seasonally or permanently; Birdlife International, 2014) were assessed. Finally, endemic species are also often sought out by tourists (Veríssimo et al., 2009). To determine whether user density was higher in IBAs that are particularly important for such species, IBAs triggered by criterion A2 (i.e. sites of importance for restricted-range species) were analyzed.

2.3. Statistical analysis

An information theoretic approach was used to explain social media user densities in IBAs globally, and within each continent and biome. In order to capture the data structure, GLMMs were fitted with both random and fixed effects. Random effects were used to represent the hierarchical structure of the data. In the global model, site (IBAs) and continent were included as random effects. In the models specific to each continent and biome group, only site was included as random effect. All variables listed in Appendix S4, Supporting information, were fitted as fixed effects, i.e. with constant regression coefficients across IBAs and countries. A Gaussian family type was used to fit the model. As values of the variables had skewness of distributions, both explanatory and response variables were log-transformed. In order to avoid multicollinearity among variables, the Corrgram package in R, with a cut-off of $r = 0.70$, was used to select variables with the strongest effect on user densities which were not correlated. To reduce uncertainty, multimodel averaging (R version 3.0.260 package “glmulti”) was implemented, allowing to average the coefficients values across the 6 best models, across all possible fitted models, ranked based on the Akaike Information Criterion. Percentage of deviance explained by each model was used as a measure of goodness of fit.

2.4. Potential pressure at site

Areas under potential pressure were identified by spatially overlapping information about user densities, classified in each quartile (from low to very high), with the intensity of threat at the site, also divided in quartiles (from low to very high) of the overall distribution of threat values.

Information about the presence and impact of different threats at each IBA was available from Birdlife International (2018b) for 33% (4044) of all IBAs. Following Salafsky et al. (2008), 13 human-induced threats were considered (list in Appendix S3, Supporting information). For each IBA, an average value of intensity across all threats was calculated in order to classify IBAs into four categories of threat intensity, according to the quartiles of the overall distribution. Areas under higher or lower pressure were then identified by combining information about classes of user density and threat intensity for each IBA.

3. Results

3.1. Visitation patterns in IBAs

A total of 1,322,591 posts generated by 130,827 users on Flickr, and 65,931,472 posts generated by 10,662,552 users on Twitter, were obtained within IBAs worldwide during 2016–2017. Mean user density across IBAs was 491 users/km^2 (from 0 to >61 million). However, the distribution of user densities was highly skewed, with only 2% of all IBAs having user densities above average, while most sites had <3.2 users/km^2 (Fig. 1). For IBAs in the top 25% of user densities (very high user density class) (Fig. 2), 45% were found in Europe, 22% in Asia, 15% in North America, and 8% in South America. Furthermore, most IBAs with very high user density were found in temperate biomes (44% of sites), followed by dry and tropical/subtropical biomes (22% and 21% respectively).

User densities were significantly different across both continents and biomes (Kruskal-Wallis test, $p < 0.001$). Specifically, user densities were higher in European and North American IBAs than in all other continents (Appendix S6, Supporting information), and in IBAs located in dry, temperate and aquatic biomes compared to those found in polar/montane and tropical/subtropical biomes (Appendix S7, Supporting information).

3.2. IBA attractiveness

Globally, the top-ranked generalized linear model (Table 1) revealed that IBAs that were important for congregatory species, with higher density of POIs, higher accessibility, higher human population density, and with fewer bird species, as well as fewer threatened bird species, had higher density of users (Table 2). No global relationship between user's density in IBA and protected area coverage, national GDP or the importance for restricted-range species was found.

The importance of predictors varied when considering separately each continent and each biome group (Appendices S8 and S9, Supporting information). While human population density, POIs and accessibility were significant predictors across all continents and biomes, other geographical and biodiversity variables varied in importance in each region (Table 2). For example, user density in European IBAs was also explained by higher GDP of countries, lower proportion of area not protected, and lower number of bird species, but higher number of threatened species. Moreover, user density was also more likely to be higher in sites important for restricted-range species in Asian IBAs, and in important sites for congregatory species in South American IBAs. Similarly, IBAs in temperate biomes that were more accessible, had higher density of POIs, were important for congregatory species, had higher density of users.

3.3. Potential pressure at sites

Among 4044 IBAs for which threats have been assessed, 17% of sites were both under very high threat and had high or very high user density (sites in dark red and dark yellow in Fig. 3). Of these IBAs, 40% were found in Europe and 35% in Asia. In particular, 30% of IBAs assessed in Europe and 18% of those in Asia were both under very high threat levels and received very high density of users.

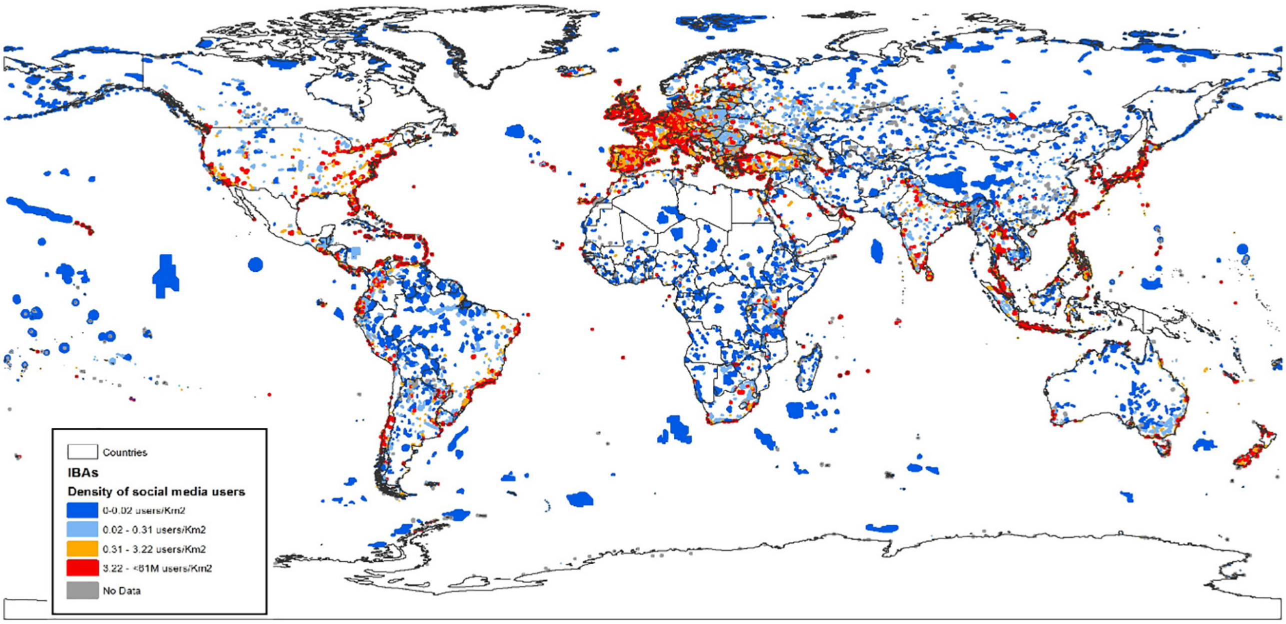

Fig. 1. Global pattern of social media user densities between February 2016 and June 2017 in Important Bird and Biodiversity Areas (IBAs) worldwide.

However, 66% of IBAs worldwide with very high and high user densities currently have not yet had data on threats integrated into the *World Database of Key Biodiversity Areas* (IBAs in dark grey in Fig. 3). Most of these were found in Europe (54%), North America (17%) and Asia (14%). Specifically, within Europe and North America, the majority (72% and 90% respectively) of IBAs with very high density of users had no threat data available.

4. Discussion

This study provides the first assessment of visitation patterns to IBAs at a global scale, using geolocated data mined from social media. The vast majority of IBAs worldwide had data from social media, but few sites had very high density of users. These heavily-used sites were mostly found in Europe and Asia, as well as in temperate biomes. In line with previous findings (Balmford et al., 2015; Hausmann et al., 2017), results showed that sites that were more accessible, had higher population density and provided more tourist facilities, such as transport and accommodation, had higher density of users. In addition, IBAs with higher user densities had lower species richness, but this is likely to be simply because tropical regions have both higher species diversity (Rahbek and Graves, 2001) and lower social media use (Hausmann et al., 2017). However, results also showed that the importance of the site for congregatory species, contributed towards explaining higher levels of user densities in IBAs, suggesting that tourists are attracted by locations of importance for particular species or wildlife spectacles (large flocks of birds, such as shorebirds, seabirds or waterbirds). Moreover, IBAs of importance for restricted-range species explained higher user densities in Asia, presumably because endemic species are particularly attractive for birdwatching activities (Steven and Castley, 2013) and may be marketed as flagship species for attracting visitors (Veríssimo et al., 2009). However, given that a number of restricted-range species and congregatory species may be sensitive to human disturbance (Burger et al., 2004), our results highlight the need to assess potential pressure at sites receiving higher density of visitors.

Highly accessible sites are also more exposed to human pressure (Burger et al., 2004), which may cause disturbance to species and the environment, threatening biodiversity (Buckley, 2011). This is especially so in sites of importance for sensitive species, such as some congregatory species (Burger et al., 2004). Our results show that higher user densities occur at sites of importance for such species. While avitourism in IBAs may help promote sustainable development, and socio-economic support to conservation (Steven et al., 2013), management actions, such as minimizing disturbance on foraging sites, building viewing platforms, and awareness raising, are likely to be important to minimize pressure, especially during migratory seasons (Burger et al., 2004). Assessing threats that tourism may have on biodiversity in highly visited places is crucial in order to develop sustainable conservation practices. IBAs that had higher user densities and were under greater threats should also be priority for management actions aimed at minimizing pressure at sites. However, data on threats do not yet exist for many highly visited IBAs, especially in North America and Europe. Mobilising such data should be priority.

Together with accessibility, socio-economic background of countries also affects tourists' visitation (Balmford et al., 2015) and social media use (Levin et al., 2015; van Zanten et al., 2016; Hausmann et al., 2017) in natural areas worldwide. Our results confirm this pattern. Results showed that GDP of countries explained user densities in IBAs only in some regions (i.e. Europe, North America, Australia & Oceania and Temperate biomes), while it was not a significant variable in other areas. A key geographical factor affecting social media use globally was, instead, the density of tourism-related POIs, with higher user densities in IBAs providing more services (e.g. restaurants, hotels, transports). Better infrastructure attracts more visitors to natural areas (Puustinen et al., 2009; De Vos et al., 2016), generating important tourism-derived income to support management and conservation (Naidoo et al., 2011). However, attention should be paid not to increase human pressure at these sites, particularly where conservation value is the highest.

As with previous studies, intrinsic biases of social media data (Kitchin, 2014; Ruths and Pfeffer, 2014), such as data quality, the representativeness of the users' population, and geographic accuracy of posts might have affected our results. Moreover, country-specific limitations in accessing social media data from most popular platforms, or limited access to internet may also limit the geographical representativeness of social media data used in this study. While these biases are less likely to affect our results due to the wide scale of the analysis, future studies should assess whether some sites currently showing lower user densities may in reality be highly visited according to social media data

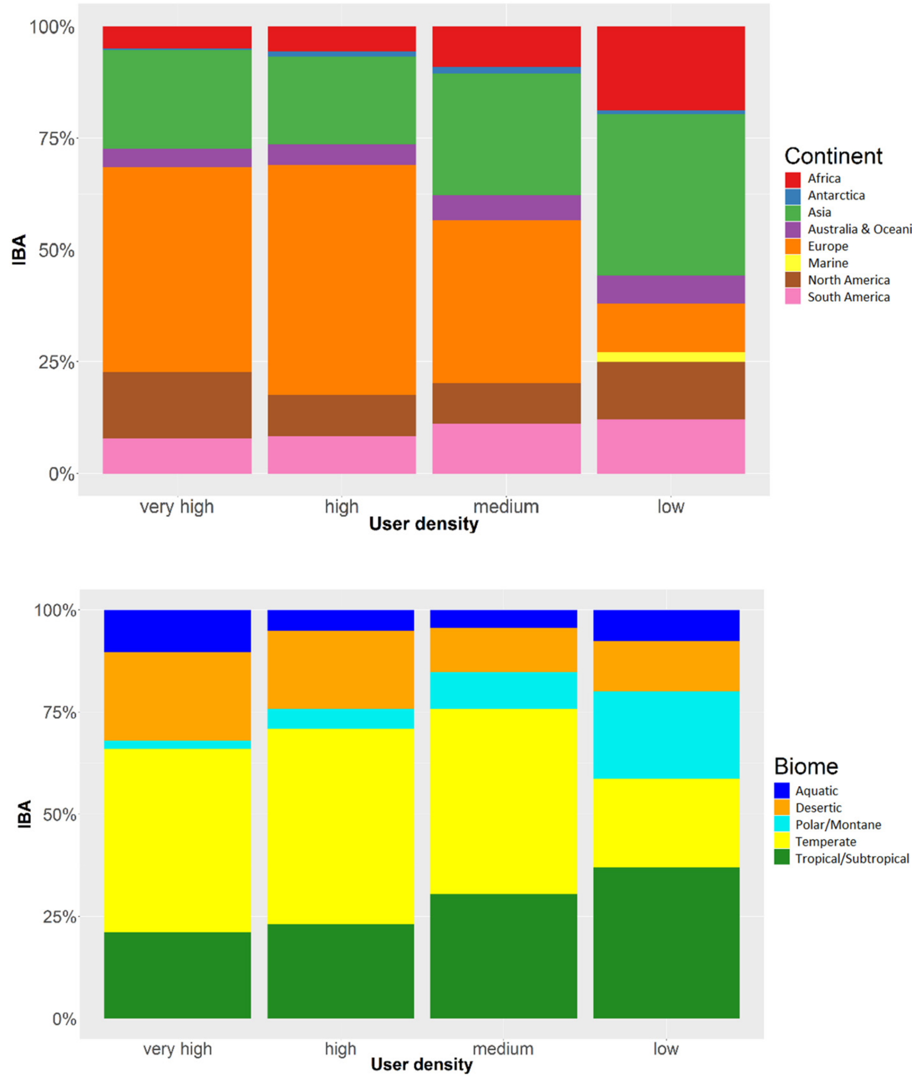

Fig. 2. Social media user density in Important Bird and Biodiversity Areas by a) continent and b) biomes (see Appendix S3).

from other platforms. Meanwhile, this study used the best available social media information globally.

5. Conclusion

By using fine-scale georeferenced data from social media, our results provide new understanding of global patterns of visitation to Key Biodiversity Areas, by revealing both popularity (recreational value) and, potentially, exposure to human pressure or benefits from human visitation in important sites for bird conservation. Our results can help prioritize monitoring and management efforts aimed at promoting opportunities to support biodiversity conservation through recreation and tourism while minimizing potential negative impacts.

Finer scale investigation of social media data, e.g. via manual (Hausmann et al., 2018) or automated (Di Minin et al., 2019) content analysis, may help understand present or emerging human-related threats at sites where threats are currently unknown or difficult to assess. Future studies may help understand human-nature interactions in IBAs better, by revealing the type of interactions (e.g. birdwatching, etc.) and preferences for biodiversity in IBAs (Hausmann et al., 2018). Moreover, assessing mobility patterns of social media users may help detect spatio-temporal hotspots of human presence within each site

Table 1
Top-ranked predictors of social media user density in IBAs globally.

Model[a]	No. of variables	AIC	Delta	% of deviance explained
Congr/Migr + Acc + Pop + POI + Spp + Spp_Threat	6	31,350.51	0	39.42%
Acc + Pop + GDP + POI + Spp + Spp_Threat	6	31,377.58	27.06	39.27%
Acc + Pop + POI + Spp + Spp_Threat	5	31,381.10	30.58	39.23%
Acc + Pop + GDP + POI + Spp	5	31,592.89	242.38	38.05%
Acc + Pop + POI + Spp	4	31,594.61	244.09	38.07%
Acc + Pop + POI + Spp + Not_Protected	5	31,596.59	246.07	38.05%

[a] "Congr/Migr" refers to sites of importance for congregatory species; "Pop" refers to human population density within 10 km buffer; "Acc" refers to accessibility; "GDP" refers to the gross domestic product per capita of the country where IBA are located; "POI" refers to density of tourism-related point of interests from Open Street Map; "Spp" refers to the count of species at sites; "Spp_Threat" refers to the count of threatened species at sites; "Not_Protected" refers to the proportion of area which is not currently covered by protected areas.

Table 2
Beta coefficients of the most important factors, explaining social media user density in Important Birds and Biodiversity Areas (IBAs), from the top ranked models globally and for each Continent and biome group.

Group		IBA count	Acc	POI	GDP	Pop density	Restricted-range	Not protected	Congr/Migr	Spp richness	Threatened spp
Global[a]		12,082	−0.198 (0.009)***	1.030 (0.063)***	0.000 (0.000)	0.298 (0.007)***	–	0.000 (0.000)	0.153 (0.020)***	−0.331 (0.019)***	−0.290 (0.019)***
Continent	Africa	1137	−0.142 (0.025)***	1.890 (0.250)***	0.017 (0.011)	0.211 (0.020)***	−0.173 (0.053) *	0.0000 (0.062)	0.001 (0.016)	−0.386 (0.0347)***	0.000 (0.027)
	Europe	4450	−0.499 (0.209)***	0.493 (0.072)***	0.034 (0.001)***	0.273 (0.015)***	0.000 (0.000)	−0.358 (0.050)***	0.000 (0.000)	−1.433 (0.046)***	0.000 (0.000)
	Asia	3134	−0.388 (0.014)***	2.189 (0.170)***	−0.000 (0.000)	0.131 (0.018)***	0.120 (0.053)*	–	0.000 (0.003)	−0.337 (0.07)***	−0.277 (0.051)***
	North America	1398	−0.149 (0.033)***	1.311 (0.238)***	0.052 (0.011)***	0.554 (0.023)***	–	0.053 (0.115)	−0.002 (0.015)	−0.577 (0.072)***	−0.153 (0.129)
	South America	1178	−0.145 (0.024)***	1.804 (0.223)***	−0.000 (0.000)	0.400 (0.020)***	−0.225 (0.049) ***	–	0.1672 (0.099)*	−0.166 (0.053)**	0.023 (0.051)
	Australia & Oceania	613	−0.205 (0.030)***	0.431 (0.029)	0.061 (0.014)***	0.262 (0.024)***	−0.221 (0.082) **	–	0.002 (0.017)	−0.262 (0.069)***	0.002 (0.017)
Biome group	Dry	1969	−0.209 (0.030)***	2.058 (0.180)***	0.007 (0.10)	0.390 (0.023)***	–	–	−0.016 (0.037)	−0.701 (0.078)***	−0.382 (0.052)***
	Polar/montane	1079	−0.095 (0.013)***	3.038 (0.279)***	−0.000 (0.001)	0.129 (0.0127)***	−0.030 (0.044)	–	0.008 (0.029)	−0.146 (0.032)***	−0.069 (0.037)
	Tropical/subtropical	3327	−0.169 (0.024)***	1.978 (0.175)***	−0.000 (0.002)	0.281 (0.017)***	0.050 (0.047)	0.024 (0.071)	–	−0.145 (0.059)*	−0.273 (0.037)***
	Temperate	4870	−0.428 (0.018)***	0.535 (0.077)***	0.068 (0.007)***	0.214 (0.014)***	0.000 (0.007)	–	0.187 (0.030)***	−0.876 (0.052)***	−0.000 (0.000)
	Aquatic	382	−0.249 (0.068)***	1.328 (0.361)***	0.013 (0.022)	0.315 (0.050)***	0.005 (0.044)	0.104 (0.215)	–	−0.220 (0.101)***	−0.220 (0.199)

Significance levels refer as '***' $p < 0.001$, '**' $p < 0.01$, '*' $p < 0.05$.
[a] Standard errors are indicated in brackets.

(Toivonen et al., 2019). Furthermore, investigating the sentiment and emotional reaction of social media users visiting IBAs may help monitor visitors´ appreciation of cultural services in the areas, as well as public response and socio-political support towards specific conservation practices (Drijfhout et al., 2016). Novel approaches and advanced computational methodologies, including machine learning and natural language processing, are available for retrieving and analyzing large amount of social media data for informing conservation science and practice (Di Minin et al., 2019; Toivonen et al., 2019).

In conclusion, geotagged social media data were used to identify IBAs where enhanced monitoring should be implemented to reduce potential visitation risks to sites of biodiversity importance and to harness the potential benefits of tourism for conservation. Our results also illustrate the significant potential for user-generated open data sources to help in monitoring sites of biodiversity importance globally.

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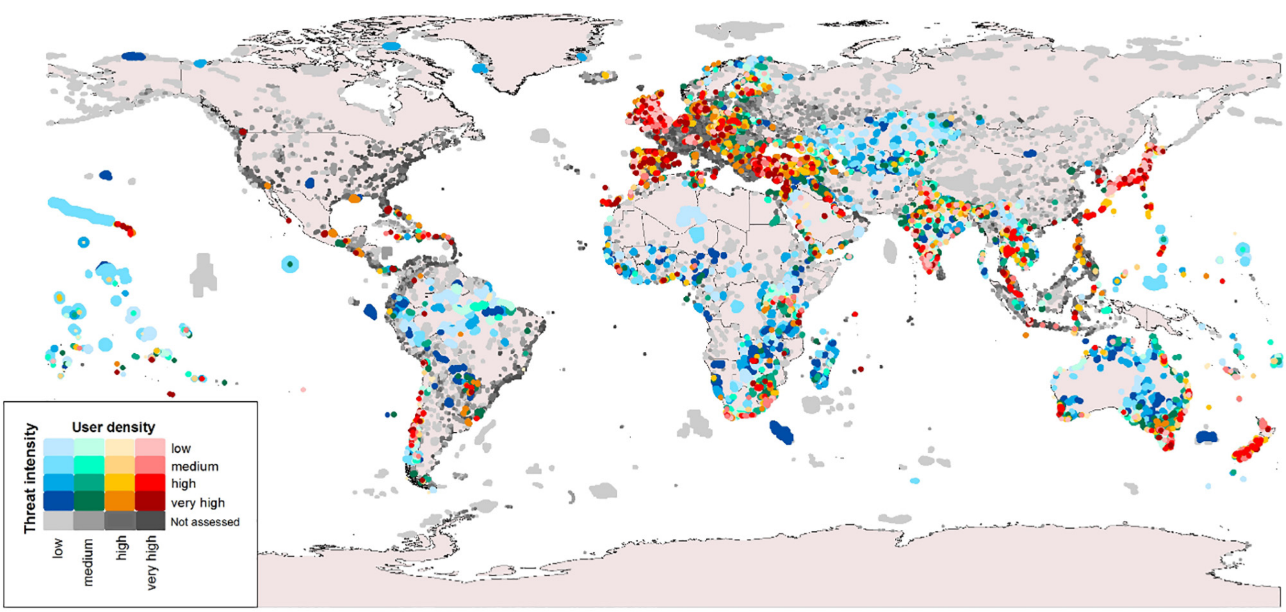

Fig. 3. Potential pressure at sites in Important Bird and Biodiversity Areas (IBAs) worldwide. Colors show intersection of IBAs falling into different quartiles of social media user densities (from blue: low density, to red: very high density) and threat intensity (from lighter colors: low threat to darker colors: very high threat). Grey scale IBAs are sites for which threats have not been assessed yet.

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Appendix A. Supplementary data

Logical framework of the study (Appendix S1), geographical continent and biome group divisions (Appendix S2), supplementary material and methods (Appendix S3), list of explanatory variables (Appendix S4), list of Point of Interests (Appendix S5), results from Kruskal-Wallis post-hoc analysis per continent (Appendix S6) and biome groups (Appendix S7), results from top ranked predictors per continent (Appendix S8) and biome groups (Appendix S9), are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of material) should be directed to the corresponding author. Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.05.268.

References

Aker, J.C., Mbiti, I.M., 2010. Mobile phones and economic development in Africa. J. Econ. Perspect. 24, 207–232.
Ballantyne, R., Packer, J., Falk, J., 2011. Visitors' learning for environmental sustainability: testing short- and long-term impacts of wildlife tourism experiences using structural equation modelling. Tour. Manag. 32, 1243–1252.
Balmford, A., Beresford, J., Green, J., Naidoo, R., Walpole, M., 2009. A global perspective on trends in nature-based tourism. PLoS Biol. 7, 1–6.
Balmford, A., Green, J.M.H., Anderson, M., Beresford, J., Huang, C., Naidoo, R., Walpole, M., Manica, A., 2015. Walk on the wild side: estimating the global magnitude of visits to protected areas. PLoS Biol. https://doi.org/10.1371/journal.pbio.1002074.
Birdlife International, 2014. Important Bird and Biodiversity Areas: A Global Network for Conserving Nature and Benefiting People. BirdLife International, Cambridge, UK Available from. http://birdlife.maps.arcgis.com/apps/MapJournal/index.html?appid=0b09be26062b4ab5b9dbb07a0e9a36a8, Accessed date: June 2017.
BirdLife International, 2017. IUCN Red List for Birds. Available from. https://www.birdlife.org/news/tag/iucn-red-list, Accessed date: November 2018.
BirdLife International, 2018a. Digital boundaries of Important Bird and Biodiversity Areas from the World Database of Key Biodiversity Areas. Page February 2018 Version. Available from. http://datazone.birdlife.org/site/requestgis, Accessed date: November 2018.
BirdLife International, 2018b. Important Bird and Biodiversity Areas factsheets. Page Available at. http://datazone.birdlife.org/site/search, Accessed date: November 2018.
BirdLife International and Handbook of the Birds of the World, 2017. Bird species distribution maps of the world. Version 6.0. Page Available at. http://datazone.birdlife.org/species/requestdis, Accessed date: November 2018.
Buckley, R., 2009. Parks and tourism. PLoS Biol. https://doi.org/10.1371/journal.pbio.1000143.
Buckley, R., 2011. Tourism and environment. Annu. Rev. Environ. Resour. 36, 397–416.
Burger, J., Jeitner, C., Clark, K., Niles, L.J., 2004. The effect of human activities on migrant shorebirds: successful adaptive management. Environ. Conserv. 31, 283–288.
Butchart, S.H.M., et al., 2012. Protecting important sites for biodiversity contributes to meeting global conservation targets. PLoS One https://doi.org/10.1371/journal.pone.0032529.
Butchart, S.H.M., et al., 2015. Shortfalls and solutions for meeting national and global conservation area targets. Conserv. Lett. 8, 329–337.
Castells, M., 2010. The information age: economy, society, and culture. The Rise of the Network Society, 1st edition vol. I. Wiley-Blackwell, Chichester 1996.
CBD (Convention on Biological Diversity), 2011. Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets. Available from. https://www.cbd.int/sp/, Accessed date: November 2018.
Cooper, M.W., Di Minin, E., Hausmann, A., Qin, S., Schwartz, A.J., Correia, R.A., 2019. Developing a global indicator for Aichi Target 1 by merging online data sources to measure biodiversity awareness and engagement. Biol. Conserv. 230, 29–36.
Correia, R.A., Jepson, P., Malhado, A.C.M., Ladle, R.J., 2017. Internet scientific name frequency as an indicator of cultural salience of biodiversity. Ecol. Indic. 78, 549–555.
De Vos, A., Cumming, G.S., Moore, C.A., Maciejewski, K., Duckworth, G., 2016. The relevance of spatial variation in ecotourism attributes for the economic sustainability of protected areas. Ecosphere https://doi.org/10.1002/ecs2.1207.
Di Minin, E., Tenkanen, H., Toivonen, T., 2015. Prospects and challenges for social media data in conservation science. Front. Environ. Sci. 3, 1–6.
Di Minin, E., Fink, C., Hiippala, T., Tenkanen, H., 2019. A framework for investigating illegal wildlife trade on social media with machine learning. Conserv. Biol. 3, 210–213.
Donald, P.F., et al., 2018. Important Bird and Biodiversity Areas (IBAs): the development and characteristics of a global inventory of key sites for biodiversity. Bird Conservation International:1–22. Cambridge University Press, Cambridge.
Drijfhout, M., Kendal, D., Vohl, D., Green, P.T., 2016. Sentiment Analysis: ready for conservation. Front. Ecol. Environ. 14, 525–526.
ESRI, 2011. ArcGIS Desktop: Release 10. Redlands. CA: Environmental Systems Research Institute Available from. http://staff.glcf.umd.edu/sns/branch/htdocs.sns/data/wdpa/, Accessed date: June 2018.
Hausmann, A., Slotow, R., Burns, J.K., Di Minin, E., 2016. The ecosystem service of sense of place: benefits for human well-being and biodiversity conservation. Environ. Conserv. 43, 117–127.
Hausmann, A., Toivonen, T., Heikinheimo, V., Tenkanen, H., Slotow, R., Di Minin, E., 2017. Social media reveal that charismatic species are not the main attractor of ecotourists to sub-Saharan protected areas. Sci. Rep. 7, 763.
Hausmann, A., Toivonen, T., Slotow, R., Tenkanen, H., Moilanen, A., Heikinheimo, V., Di Minin, E., 2018. Social media data can be used to understand tourists' preferences for nature-based experiences in protected areas. Conserv. Lett. 11, e12343. https://doi.org/10.1111/conl.12343.
Heikinheimo, V., Di, Minin E., Tenkanen, H., Hausmann, A., Erkkonen, J., Toivonen, T., 2017. User-generated geographic information for visitor monitoring in a national park: a comparison of social media data and visitor survey. ISPRS Int. J. Geo-Inf. 6, 85.
IUCN, 2016. A Global Standard for the Identification of Key Biodiversity Areas: Version 1.0. Page. 1st edition. IUCN, Gland, Switzerland Available from. https://portals.iucn.org/library/node/46259, Accessed date: November 2018.
Joppa, L.N., et al., 2016. Filling in biodiversity threat gaps. Science 352.
Kitchin, R., 2014. Big Data, new epistemologies and paradigm shifts. Big Data Soc. https://doi.org/10.1177/2053951714528481.
Ladle, R.J., Correia, R.A., Do, Y., Joo, G.J., Malhado, A.C.M., Proulx, R., Roberge, J.M., Jepson, P., 2016. Conservation culturomics. Front. Ecol. Environ. 14, 269–275.
Levin, N., Kark, S., Crandall, D., 2015. Where have all the people gone? Enhancing global conservation using night lights and social media. Ecol. Appl. 25, 2153–2167.
Naidoo, R., Weaver, L.C., Stuart-hill, G., Tagg, J., 2011. Effect of biodiversity on economic benefits from communal lands in Namibia. J. Appl. Ecol. 48, 310–316.
Puustinen, J., Pouta, E., Marjo Neuvonen, M., Tuija Sievänen, T., 2009. Visits to national parks and the provision of natural and man-made recreation and tourism resources. J. Ecotourism 8, 18–31.
R Development Core Team, 2013. R: The R Project for Statistical Computing. Page R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria Available from. https://www.r-project.org/, Accessed date: April 2016.
Rahbek, C., Graves, G.R., 2001. Multiscale assessment of patterns of avian species richness. Proc. Natl. Acad. Sci. U. S. A. 98, 4534–4539.
Richard, D.R., Tunçer, B., 2017. Using image recognition to automate assessment of cultural ecosystem services from social media photographs. Ecosyst. Serv. 31, 318–325.
Roll, U., Mittermeier, J.C., Diaz, G.I., Novosolov, M., Feldman, A., Itescu, Y., Grenyer, R., 2016. Using Wikipedia page views to explore the cultural importance of global reptiles. Biol. Conserv. 204, 42–50.
Ruths, D., Pfeffer, J., 2014. Social media for large studies of behavior. Science 346, 1063–1064.
Salafsky, N., et al., 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conserv. Biol. 22, 897–911.
Siikamäki, P., Kangas, K., Paasivaara, A., Schroderus, S., 2015. Biodiversity attracts visitors to national parks. Biodivers. Conserv. 24, 2521–2534.
Steven, R., Castley, J.G., 2013. Tourism as a threat to critically endangered and endangered birds: global patterns and trends in conservation hotspots. Biodivers. Conserv. 22, 1063–1082.
Steven, R., Castley, J.G., Buckley, R., 2013. Tourism revenue as a conservation tool for threatened birds in protected areas. PLoS One https://doi.org/10.1371/journal.pone.0062598.
Tenkanen, H., Di Minin, E., Heikinheimo, V., Hausmann, A., Herbst, M., Kajala, L., Toivonen, T., 2017. Instagram, Flickr, or Twitter: assessing the usability of social media data for visitor monitoring in protected areas. Sci. Rep. 7, 17615.
Tittensor, D.P., et al., 2014. A mid-term analysis of progress toward international biodiversity targets. Science 346, 241–244.
Toivonen, T., Heikinheimo, V., Fink, C., Hausmann, A., Hiippala, T., Järv, O., Tenkanen, H., Di Minin, E., 2019. Social media data for conservation science: a methodological overview. Biol. Conserv. 233, 298–315.
UNEP-WCMC, 2014. The World Database on Protected Areas (WDPA). [On-line], [November 2016]. UNEP-WCMC, Cambridge, UK Available at:. www.protectedplanet.net.
van Zanten, B.T., van Berkel, D.B., Meetemeyer, R.K., Smith, J.W., Tieskens, K.F., Verburg, P.H., 2016. Continental scale quatification of landscape values using social media data. PNAS 113, 12974–12979.
Veríssimo, D., Fraser, I., Groombridge, J., Bristol, R., MacMillan, D.C., 2009. Birds as tourism flagship species: a case study of tropical islands. Anim. Conserv. 12, 549–558.
Weiss, D.J., et al., 2018. A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature 553, 333–336.
Wood, S.A., Guerry, A.D., Silver, J.M., Lacayo, M., 2013. Using social media to quantify nature-based tourism and recreation. Sci. Rep. 3, 2976.